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The U.S. Planetary Exploration Program

Robert J. Parks

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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The U.S. planetary exploration program

The goal—a comprehensive knowledge of translunar and interplanetary space by 1970—will necessitate developing new families of instruments, better thermal-control systems, and more reliable spacecraft

By Robert J. Parks

NASA JET PROPULSION LABORATORY, PASADENA, CALIF.

Robert J. Parks is planetary programs director for the Jet Propulsion Laboratory, responsible for NASA-JPL's unmanned missions to the planets and interplanetary space. After receiving a B.S. in electrical engineering from CalTech in 1944, he served with the Army Signal Corps for 2½ yr, eight months with U.S. Occupation Forces in Germany. He was associated briefly with Hughes Aircraft as a radio engineer, and then joined JPL in 1947. He was JPL's program director for the Army's Sergeant field ballistic missile, described by military experts as "America's first truly 'second generation' surface-to-surface tactical missile," as well as chief of the JPL group for research and development of missile guidance systems, communications, and tracking.

THE UNITED STATES is planning the exploration of the near planets and interplanetary space in the decade 1960–70, using presently available launching vehicles and other, more-advanced systems due to reach the firing pad later in this decade.

As the cognizant U.S. agency for nonmilitary space operations, NASA has assigned to the Jet Propulsion Laboratory of California Institute of Technology the responsibility for both the lunar and planetary unmanned exploration programs. Centaur and Saturn launching vehicles have been allocated for use in the planetary programs and will be furnished by Marshall Space Flight Center.

Preliminary design of the first U.S. spacecraft was concluded in late 1960, and the detail design, engineering, hardware fabrication, and test stages are in process for early planetary and interplanetary missions. Other follow-on projects are in the preliminary study phase.

Program Objectives

The primary long-range objective of our planetary and interplanetary programs is the development of automatic, unmanned spacecraft technology and its application in spaceprobes to gather fundamental scientific knowledge concerning the planetary environments, the planets themselves, and solar phenomena, both within and out of the plane of the ecliptic (earth's orbital plane).

The secondary long-range objectives of the program are the development of technology and the collection of scientific data which will contribute to the eventual manned exploration of the planets and interplanetary space.

By 1970, the goal is to have demonstrated and exploited, in terms of acquired scientific data, spacecraft capable of orbiting Mars and Venus and of landing on the surfaces of these planets. Futhermore, it is planned by 1970 to initiate programs for probing the planets Mercury and Jupiter and for penetrating interplanetary space out of the plane of the ecliptic.

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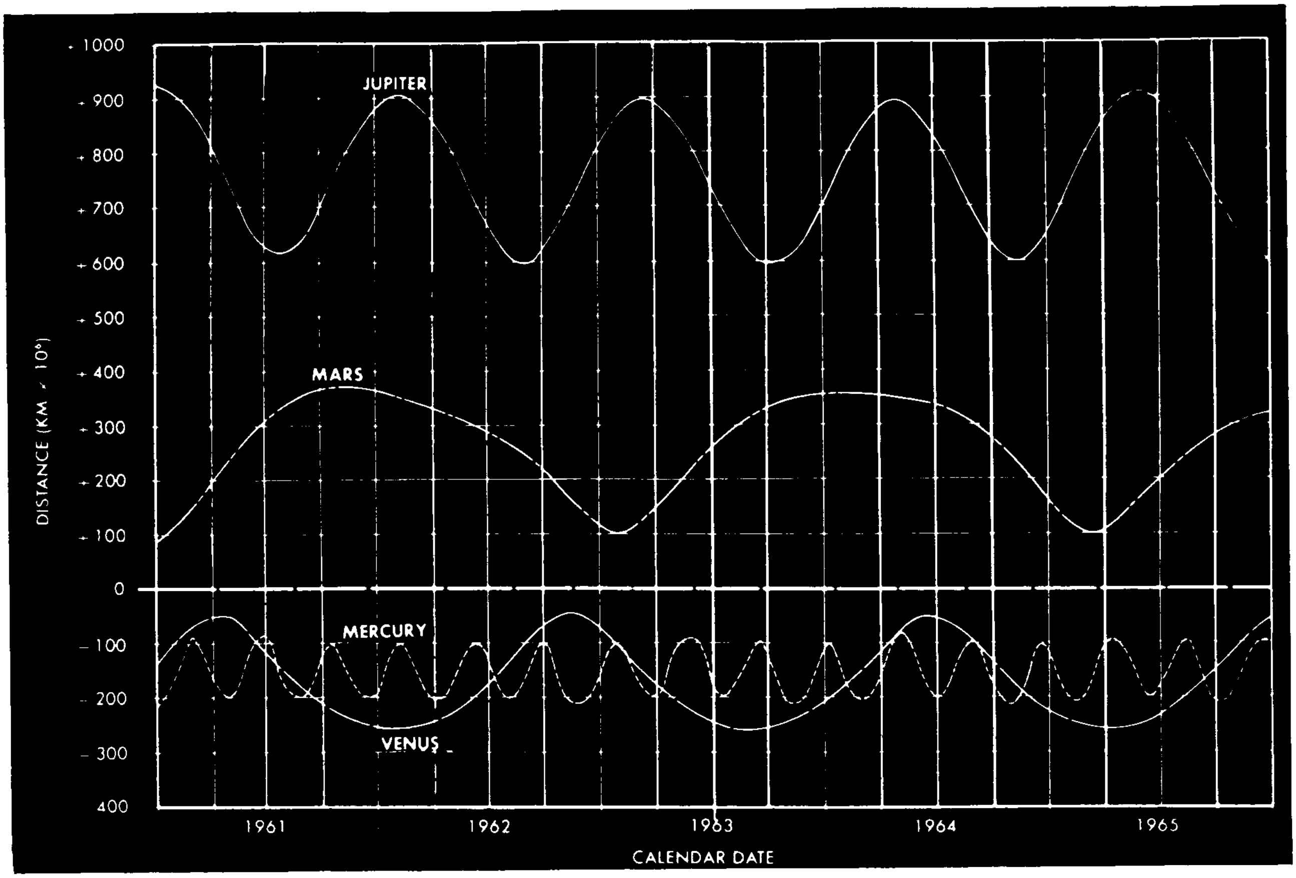
Relative Distances and Periods of Planets



Scientific Goals

The broad scientific objectives of the program relate to answering the following two questions:

Is extraterrestrial life present on the near planets?

What can be learned of the origin and evolution of the solar system and its multitude of component bodies?

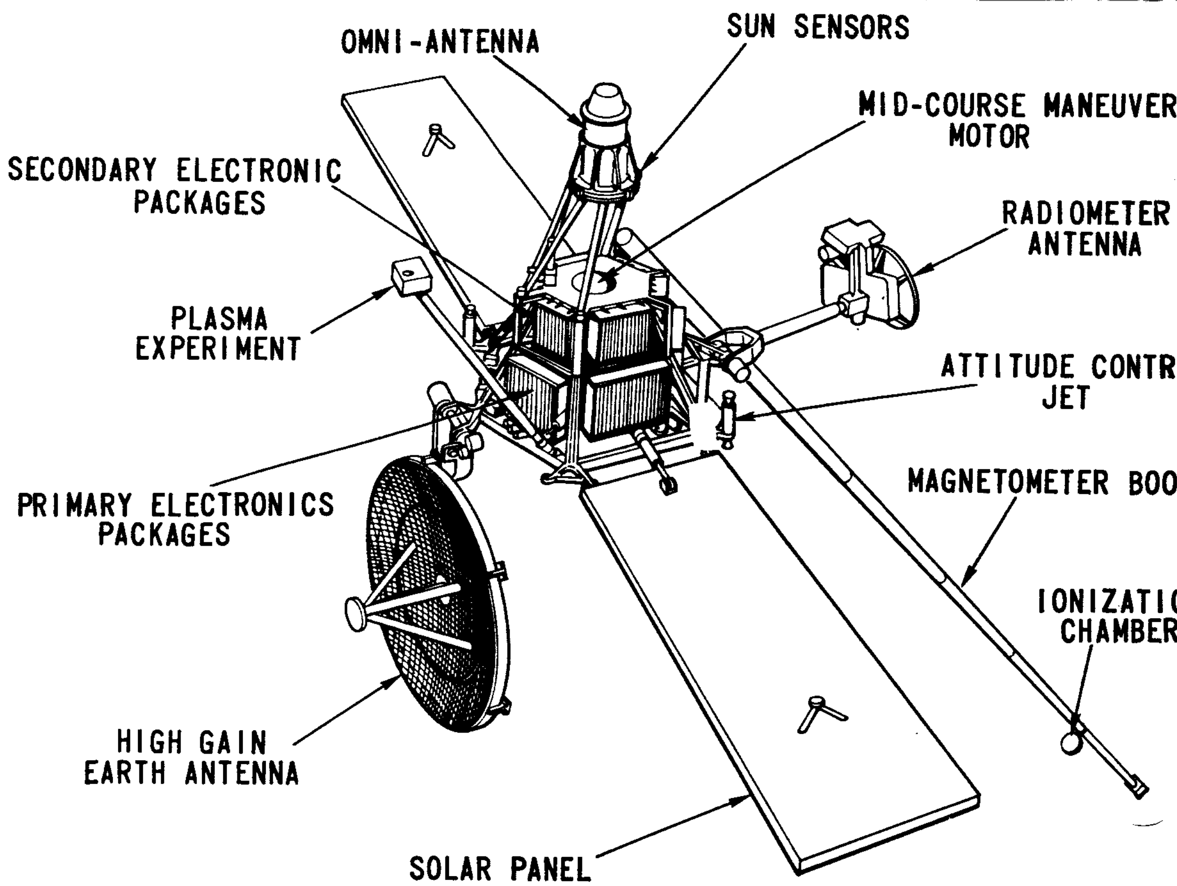
The discovery of life on another planet would be one of the most momentous events in human history. More than answering a universal curiosity, such a discovery would also be of enormous scientific interest. Next to the synthesis of living matter in the laboratory, it would be the one most important steps toward an understanding of the origin of life.

Much must be accomplished in the investigation of the physical nature of the planets. Little is known about Venus other than its mass and trajectory. It has an atmosphere that is visually opaque, but the reason for this opaqueness is not known. Its atmosphere is known to contain at least 500 times the amount of carbon dioxide as the atmosphere of earth. There is a small amount of water vapor above the reflecting layer but the total water content is still unknown. The surface and atmospheric temperatures, the atmospheric constituents, the rotation rate, and the spin axis are typical items of fundamental importance that must be determined.

The changing character of its surface is the central question concerning Mars. The simplest explanation relates this phenomenon to some life process, which must have some interaction with the planet's atmosphere. Thus, some of the most important information that the first Mars missions can obtain concerns its atmospheric constituents and the possible existence of organic molecules on its surface.

Many of these basic measurements of the general characteristics of the planets' surfaces and atmospheres are not only of direct and immediate scientific value, but are required for the design of the entry and landing spacecraft that will be launched by the Saturn vehicle. These spacecraft will be necessary for the detailed and unambiguous measurement of the phenomena of the planets. Even the magnetic-field and particle-measurement experiments proposed for the first Venus missions have relevance in the design of future communication systems.

In other words, early priority must be given to measurements which are required to design the follow-on spacecraft.



The Mariner Interplanetary Spacecraft

Restraints

Program plans have been influenced by such restraints as planet availability, launch-vehicle availability and capability, and spacecraft technology.

The chart on page 23 shows in a general way the proximity of the planets to earth and the periods of launch availability. Launch opportunities will consist roughly of a 1- to 2-hr period each day for approximately 1 month in each period of planet availability.

When the launching of a satellite or a lunar mission slips a month, a simple 1-month delay is introduced into the program. Significantly, in the case of a planetary mission, a 1-month slip usually will mean that another favorable launch opportunity will not be available *for a year or more.* Reliability thus assumes paramount importance at the launch complex and in flight.

DSIF Station Locations

Station Location	Latitude	Longitude
Goldstone	35.389 deg N	116.848 deg W
Woomera	31.417 deg S	136.867 deg E
South Africa	25.891 deg S	27.675 deg E

The high order of complexity of planetary and interplanetary spacecraft is evidenced by the following typical restraints:

Communications. The spacecraft must be able to communicate engineering and scientific data (both in interplanetary space and in the vicinity of the target planet) to earth over extreme distances. Because of such distances, the transmitting equipment must utilize a directional antenna oriented toward earth. Two-way communications are necessary for precision tracking to determine orbits, to receive telemetry, and to transmit commands to the spacecraft in flight.

Guidance and Control. The spacecraft must approach closely enough to the target planet to make meaningful observations. This restraint requires adequate flight-path guidance as well as midcourse and perhaps terminal propulsion systems.

Directional Measurements. In order to make observations upon the target planet, the spacecraft must be able to detect the planet and properly align its scientific instruments.

Attitude Control. The spacecraft must be stabilized in space and controlled in attitude in order to execute proper orbit-correction maneuvers, to point solar panels toward the sun, to orient a directional antenna toward earth, and to align instruments with the planet. The sun will be used as one reference and either the earth or a star will be the reference for the third, or roll, axis.

Program Plans

The planetary program is divided into projects, dependent upon mission, spacecraft design, launch vehicle, and budget considerations. Venus and Mars missions utilizing the Centaur launch vehicle form the Mariner series. The first planetary mission employing Saturn will begin the Voyager series.

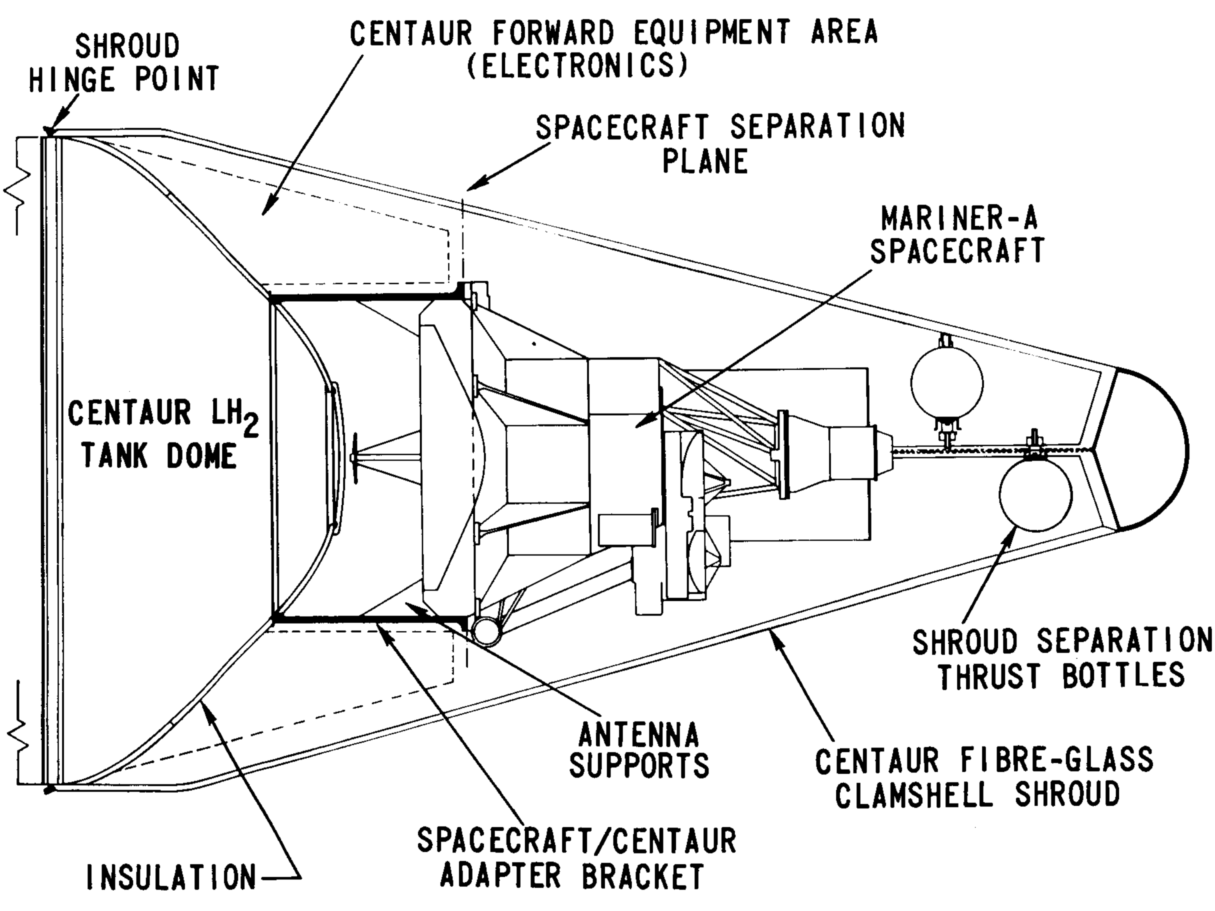
A major objective of the program involves successful Mars and Venus missions in 1964. To ensure reasonable confidence in these missions, spacecraft developmental flights are planned, starting in 1962.

An example of the type of developmental flights planned is an actual planetary flyby mission to approach within a nominal value of approximately 27,000 meters of the center of Venus in 1962, with a transit time in excess of 3 months. Another example would be the launch of a deep-space probe on a planetary-like trajectory outside the periods of Venus or Mars availability. Such a flight would provide flight-test experience with most of the spacecraft equipment and (CONTINUED ON PAGE 52)

Venus and Mars Mission Opportunities

1960 —		MARS
1961 —	VENUS	
1962 —	VENUS	MARS
1963 —		
1964 —	VENUS	MARS
1965 —	VENUS	
1966 —		MARS
1967 —	VENUS	
1968 —		MARS
1969 —	VENUS	
1970 —	VENUS	

Mounting of Mariner in Centaur Nose Cone



U.S. Planetary Exploration

(CONTINUED FROM PAGE 25)

would furnish passenger room for interplanetary scientific experiments. A third developmental flight could be launched into an earth-return orbit to permit the testing of specialized items such as planet seekers and orientation equipment, planetary scientific instruments, and earthbound approach-guidance techniques.

In addition to the 1964 missions, additional Mariner flights are scheduled during the Mars and Venus opportunities in the years 1965 and 1966.

The first of the Saturn vehicle flights in the planetary-interplanetary program will be launched in the middle of this decade to begin the Voyager series. Possible missions for this initial flight include an advanced flyby, an orbiter, or a split-capsule lander. Beyond this time, the Voyager spacecraft is expected to evolve into a full series of sophisticated orbiters and landers, launched by the C-2 Saturn with Venus and Mars as primary targets.

Planetary orbiters are a necessary phase of the evolution because they are a logical step in the development of spacecraft technology; they are probably required to permit sufficient observation of the planet to determine locations and procedures for landing experiments; and they may constitute an important step in the actual landing experiment (orbital relay of information from the lander to earth).

Mariner Spacecraft

The preliminary design phase of the first Mariner spacecraft has been completed. The drawing on page 25 illustrates the spacecraft housed in the Centaur nose cone; the drawing on page 24 shows its spaceflight configuration; and the chart below right indicates a typical trajectory for a Venus mission.

The midcourse maneuver required for adequate flight path accuracy in the approach to Venus would be performed somewhat in the following manner. Accumulated perturbations and variances from the planned trajectory would be measured up to approximately 42 hr after launch. From this data, a corrective maneuver would be computed and transmitted to the spacecraft. A second command would direct the spacecraft to initiate the maneuver, and the following sequence of events would occur, in the order listed:

1. The antennas would be positioned to remove the high-gain directional antenna from the rocket-motor exhaust and to assure accurate CG location during firing.
2. The spacecraft gyros would be precessed to the calculated position for the maneuver, simultaneously causing the vehicle to follow the gyro precession.
3. The midcourse rocket motor would be ignited when the spacecraft oriented to the proper thrust vector.
4. Motor thrust would be terminated when the spacecraft incremental velocity, as measured by the integrated output of an axial accelerometer, equaled that of a velocity parameter previously transmitted as part of the midcourse maneuver command.
5. The antenna would be re-positioned.
6. The sun and earth would be reacquired and the proper spacecraft attitude re-established through the use of the attitude-control jets.

After completion of the midcourse maneuver, the spacecraft would again enter the cruise phase, which would be maintained until shortly before encounter with the target planet, Venus.

Typical scientific experiments to be carried on board the Mariner spacecraft for a Venus mission include the following:

1. Measurement of magnetic fields in interplanetary regions and in the vicinity of Venus.
2. Measurement of particles and high-energy radiation in the interplanetary regions and in the vicinity of Venus.
3. Measurement of mass and velocity distribution of dust particles in the interplanetary regions and in the vicinity of Venus.
4. Study of atomic, molecular, and ionic species in the atmosphere of Venus.
5. Measurement of temperature distribution on the surface and in the atmosphere of Venus.
6. Deduction of as much of the physical properties of the surface of Venus from these measurements as possible.

A data automation system would be carried to provide a data programming system for the scientific instruments as well as the required data storage. A predetermined program would be inserted into the automation system, with an automatic override to provide a suitable change in measurements if, for example, a solar flare should occur during the flight.

At the start of a typical planetary encounter sequence, the horizontal platform (an articulating, pointable head for the scientific instruments) would be oriented to the preset acquisition position, and antenna reference angles for the encounter would be established. The horizon scanner would then be placed in operation, planet search would be initiated and would continue until planet acquisition was accomplished, and planetary tracking would commence. The radiometer would be activated at approximately 150,000 km from the planet and would scan the target as the spacecraft passed. This experiment would continue to approximately 150,000 km past the planet. Scanning for the ultraviolet experiment would begin at about 60,000 km from the target and would continue through the encounter until the spacecraft was approximately 60,000 km past the planet. Nearest approach to the planet for this design would approximate 27,000 km.

Scientific data stored during the encounter would be transmitted back to earth on the two days immediately following the flyby. On the fourth day after encounter, an advanced development experiment could be performed, involving restart of the midcourse motor, with the spacecraft attitude such that the high-gain antenna could remain oriented toward earth during burning without entering the exhaust envelope.

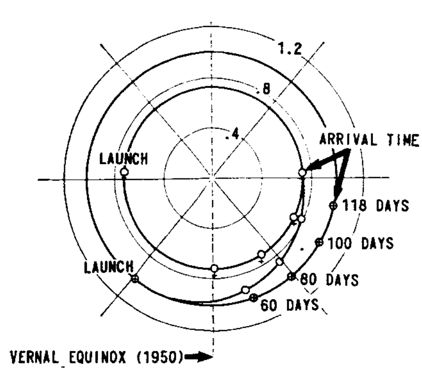
Communications and Data Return

An integral requirement in scientific investigation of outer space is a precision tracking and communications system capable of providing coordinated tracking, command, and telemetering functions for the space probe. A Deep Space Instrumentation Facility (DSIF) has been established to satisfy this requirement of the lunar and planetary programs.

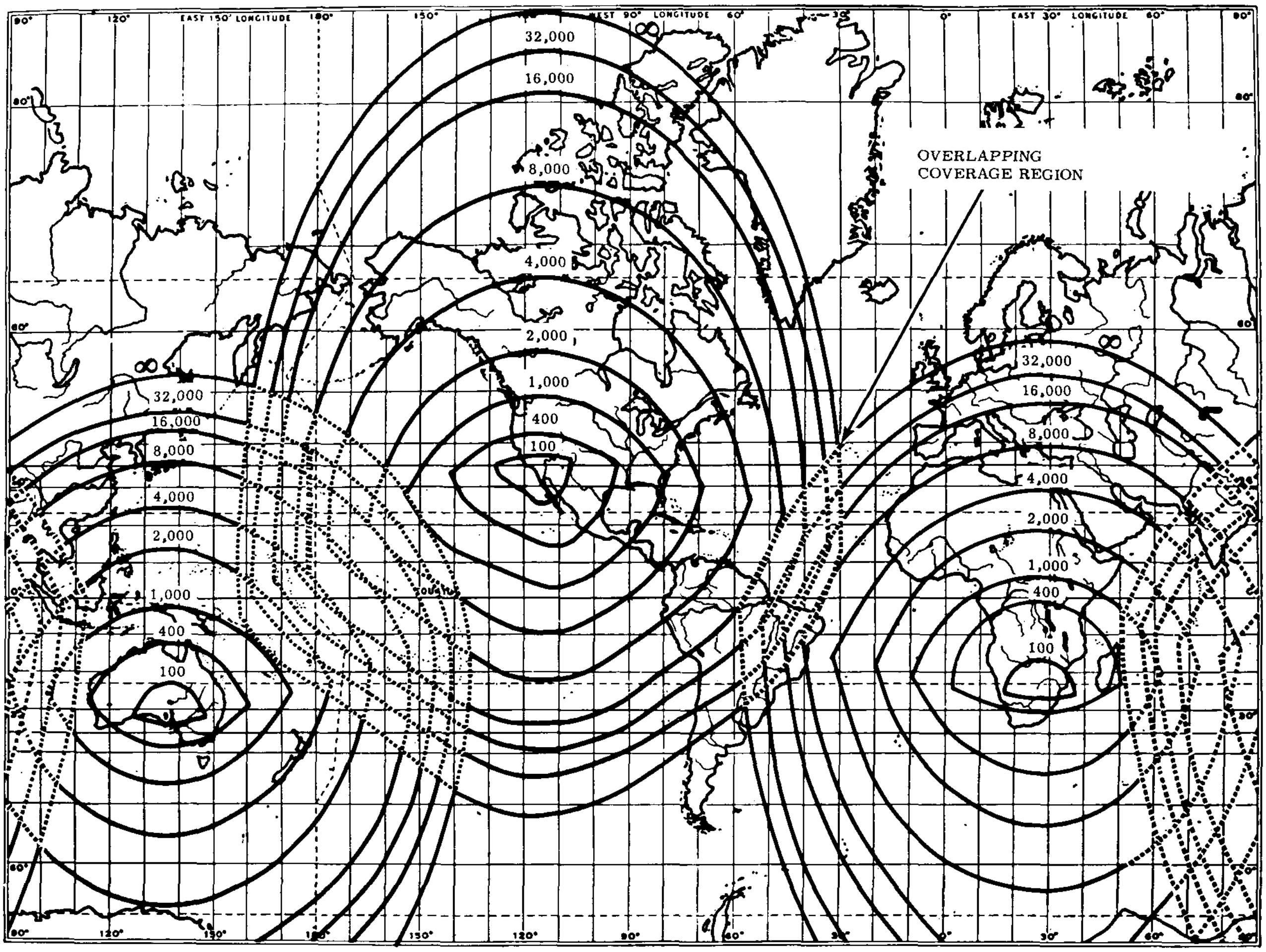
The DSIF net is comprised of three deep-space stations, one or two mobile stations, and the intersite communication links permitting data transfer and administration of operations. The DSIF stations are presently equipped with 85-ft-diam reflectors. A mobile station, equipped with a 10-ft-diam reflector, is used mainly for command, telemetering, and tracking of space probes from injection to over 10,000-mi altitude.

The DSIF design philosophy provides a precision radio tracking sys-

Mariner Flight to Venus



DSIF Coverage



Note: The chart gives the locus of subvehicle points for horizon visibility at given altitude in statute miles.

tem for measuring two angles, radial velocity, and range, and then utilizes this tracking system to send radio commands and to receive radio telemetry in an efficient and reliable manner. The DSIF net is scheduled to undergo long-term improvement and modernization, consistent with advancement in the state of the art and spacecraft requirements.

In addition to its participation as a member of the DSIF, JPL's Goldstone station is utilized for extensive research and development in space tracking and communications, and, in most cases, new equipment will be installed and tested at Goldstone before it is integrated into the DSIF net.

The three deep-space stations are located at approximately equal intervals of longitude around the earth, as shown in the table on page 24. The mobile station will be emplaced near the mission injection points, which tend to be centered in the southern hemisphere.

The loci of subvehicle points with 5-deg horizon mask angles at Woomera and Johannesburg, and the natural mask at Goldstone, are shown on page 54. This figure indicates the field of view of each deep-space station as a function of vehicle altitude, and it also shows the regions of overlapping coverage. The field of view of mobile stations is usually unrestricted because of normal emplacement in elevated locations.

Technological Problems

Some of the more significant technological barriers peculiar to the planetary-interplanetary program are as follows:

Launch on Time. This problem cannot be overemphasized. The launch-on-time restraint means that schedules *must* be met and that equipment *must* be reliable, both in prelaunch operations and the flight environment. The equipment must also have the capability of simple checkout, and parameters must be easily reset, where necessary, so as not to restrict the launch window.

Long Life. The mission flight times even to the nearer planets will vary from a minimum of about 3 months to perhaps several years. Equipment obviously must be designed and built for long life under the extreme environmental conditions of space.

Power. Because of the long-life requirement and weight limitations, it is necessary, for at least the next several years, to use solar panels as the primary and sustaining power sources for spacecraft. Solar panels must be oriented toward the sun, with batteries occasionally backing up certain maneuvers. Use of more-or-less standard spacecraft for different missions toward and away from the sun imposes certain general engineering problems. For example, approximately two to three times as much solar collecting area for the same power is required in the vicinity of Mars as in the region of Venus.

Temperature Extremes. Passive emissivity and absorptivity surface-treatments are considered inadequate to permit spacecraft electronic equipment to operate for the required lifetime of a planetary or interplanetary mission under the expected temperature extremes. The design of suitable thermal-control systems for missions toward and away from the sun poses a challenging engineering problem.

Communication. The communication distances for spacecraft in the vicinity of Venus and Mars will be on the order of 30 to 100 million miles; Jupiter and other targets will be appreciably farther. There is a need for efficient high-power transponders and for large yet stowable antennas with proper high-gain, directional characteristics. In flyby experiments, a considerable amount of data must be gathered in a brief time of encounter near the planet. This data can be stored during the encounter, but it may require days to transmit the same information back over the long communication path to earth.

Design Adequacy. Planetary opportunities are few and launch vehicles and spacecraft are expensive. Space exploration will not have the benefit of nearly as many developmental launchings preceding a particular mission as have military rockets and launch vehicles in the past. Fabrication and testing techniques must be thorough and well planned, and a very high order of reliability must be designed into the spacecraft.

Sterilization. It is national policy to prevent the contamination of a target planet or its atmosphere by U.S. spacecraft. Although early missions are planned as intentional planet flybys, later landing or atmospheric-entry experiments will require development of effective sterilizing techniques, consistent with manufacturing and launching operations.

Instruments.. Families of instruments must be devised to conduct the exploration of space and the planets with the capability of flexibility of measurements. These instruments must be engineered with the same considerations of reliability, environment, and operational concepts that are given the other elements of the spacecraft systems.

By 1970, the U.S. planetary-interplanetary program should provide comprehensive knowledge of translunar and interplanetary space, and should make a vigorous start in probing the intriguing mysteries of the near planets and the extra-ecliptic regions.

Exotic new propulsion systems, such as nuclear-electric propulsion, will lift much heavier, more complex payloads and deliver them with extreme accuracy.

From these beginnings, the last 30 yr of the century may well bring man near the solution to some of the ultimate questions that have excited him since he first became aware of the environment beyond earth. ♦♦